# COMPUTER CODES FOR THE EVALUATION OF SPACE RADIATION HAZARDS

## VOL. 3 APOLLO SECTOR ANALYSIS

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## INTRODUCTION

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In order to determine if additional shielding against space radiation is necessary in certain areas of a spacecraft, a detailed sector analysis is required. The spacecraft's inherent radiation shielding for each sector, the body tissue thickness in each sector, and the fractional solid angle for each sector are inputs for computer programs which calculate the dose at a specified body point. Three body points were used and the average tissue thickness for each solid angle as defined by NASA was determined.

Author

## METHOD OF DETERMINING TISSUE THICKNESS FOR EACH SOLID ANGLE

For determining tissue thicknesses at a specific body point, a map of the solid angles prescribed by NASA was used as an overlay on the tissue isothickness curves of D. L. Dye (Ref. 1). However, because of the different reference axes used in defining the angles of direction or solid angles about a point, it was necessary to make a transformation. Specifically, a direction or solid angle, $(\Psi, \theta)$ defined by NASA was transformed to that of $\theta, \phi$ as described in Ref. 1. In order to avoid confusion of the two $\theta$'s, NASA's $\theta$ was redesignated $\omega$. Thus, the transformation is one from $\psi, \omega$ to $\theta, \phi$.

Referring to Fig. 1, a satisfactory transformation was obtained by using the following equations as a pair:

$$\tan \phi = \frac{QR}{OR} = \frac{PR}{OR}\frac{QR}{PR} = \tan\omega \sin\Psi$$

$$\tan \theta = \frac{PQ}{OQ} = \frac{PR}{OR}\frac{OR}{OQ}\frac{PQ}{PR} = \tan\omega \cos\phi \cos\Psi$$

Hence, given a solid angle outlined by $\omega_1$, $\omega_2$, $\Psi_1$, and $\Psi_2$, where the $\Psi$'s are angles measured from the z-axis in the y-z plane such that $\Delta\Psi = \Psi_2 - \Psi_1$, and the $\omega$'s are $\theta_1$ and $\theta_2$ as given by NASA, a $\theta, \phi$ map of the solid angle can be obtained. Figure 2 is an example of such a map.

To facilitate matters, a short computer program has been written for the transformation (this is described in the appendix). In this program, one needs only to feed in the $\omega$'s and $\psi$'s and the corresponding $\theta$'s and $\phi$'s are returned. However, due to the program's limitation, all angles $\omega, \Psi$ are made to be



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between 0 and 90 degrees. For example, when $\omega$ is between 90 and 180 degrees, $180-\omega$ is used. Plotting on a $\theta, \phi$ map is accomplished by noting in which quadrant a particular solid angle falls. It is not necessary to feed into the program the angle $\omega = 90°$, since it is easily seen from the geometry that when $\omega = 90°$, then $\phi = 90°$, and $\theta = 90° - \psi$.

Once the $\theta, \phi$ map of the solid angles has been established, it is superimposed on the tissue isothickness curve of the specific body point, and the average tissue thickness for each solid angle is obtained. If greater accuracy is desired when large variations occur in tissue thickness in a solid angle, the solid angle should be further subdivided.

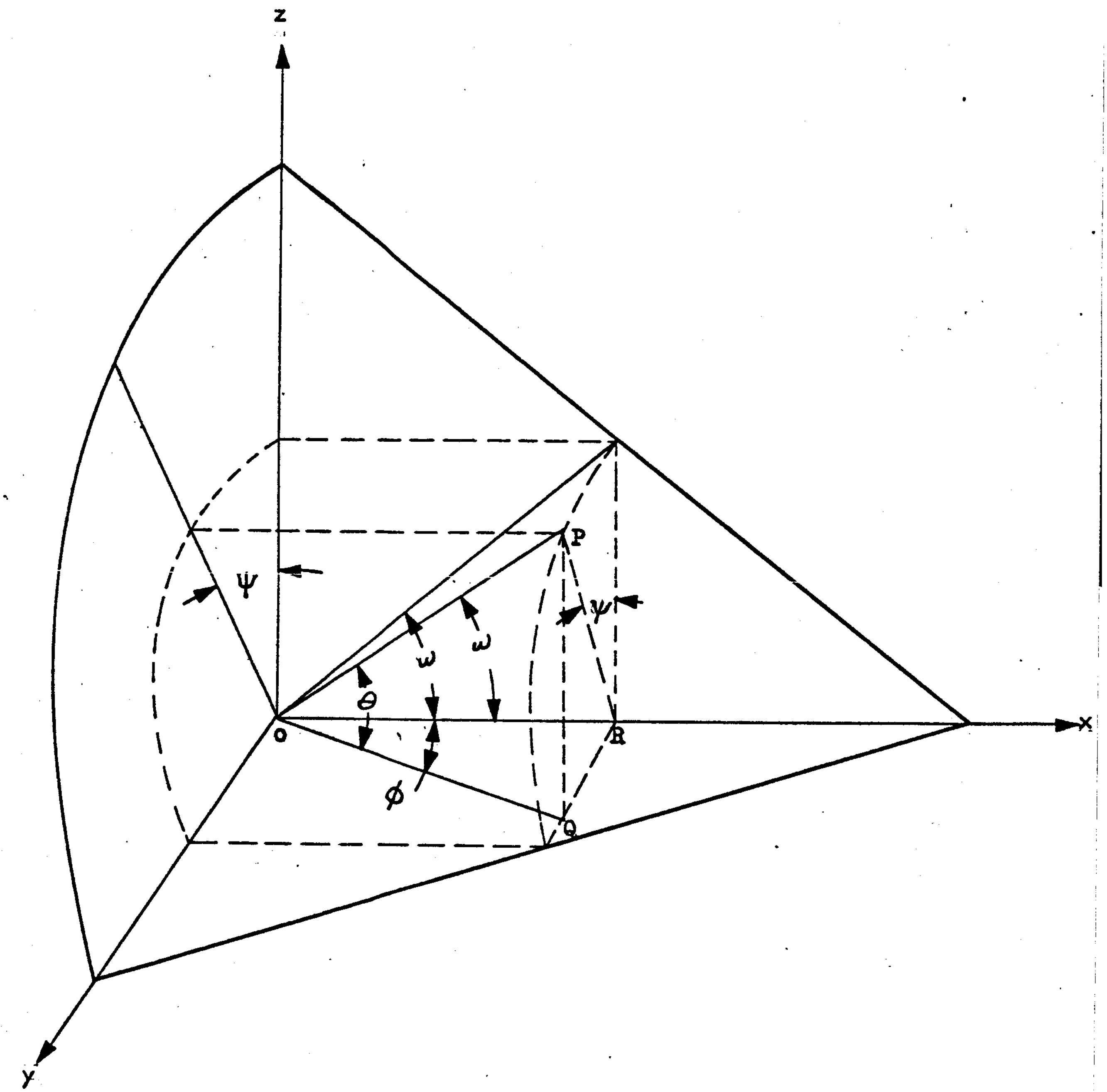


FIGURE 1. Geometry of NASA and Boeing coordinate system.

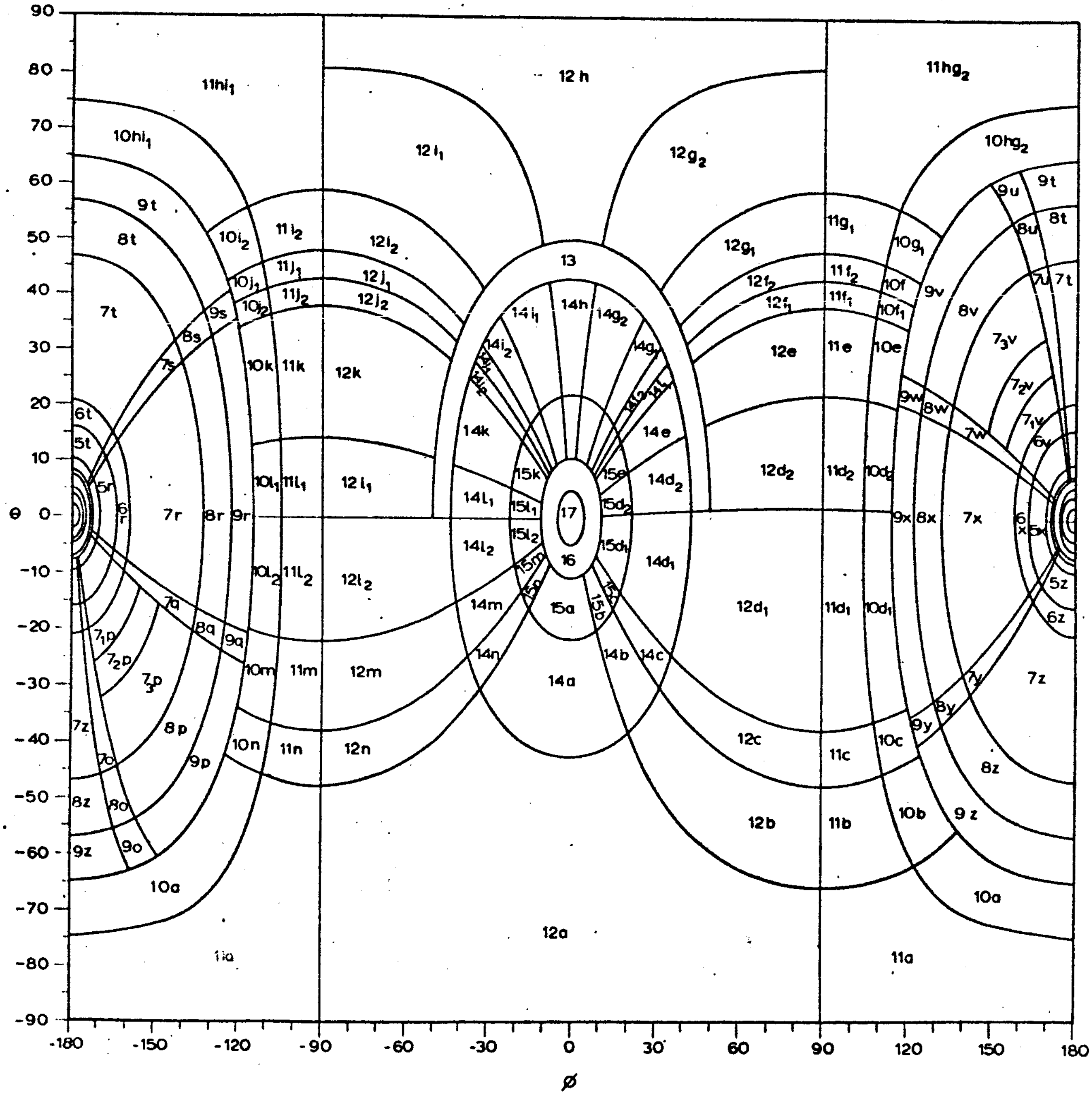

FIGURE 2. Map of solid angles.

## APOLLO ANALYSIS

The first step in this analysis was determination of the angles $\psi$ from the given values of $\Delta\Psi$. For lack of additional information it was assumed that for the command module the sections g and i were equal, $g_1$ and $i_2$ were equal, and that the z-axis divided the section h in half. For the service module, it was assumed that the sections r and x were equal, s and u were equal, and o, q, and y were equal. Further, after measuring the drawing supplied, the section o was taken to start at 10 degrees from the z-axis. Once these assumptions were made, Figs. 3 and 4 with the angles $\psi$ were easily obtained. These values of $\psi$ along with the values of $\omega$ can then be fed directly into the computer program for transformation to the corresponding values of $\phi$ and $\theta$.

These values of $\phi$ and $\theta$ are plotted on transparent paper to form a map (Fig. 2). This map was then placed over the tissue isothickness plots of the three specified body points, and the average tissue thickness for each solid angle was listed. In cases where the solid angle is composed of a group of sections (for example, the solid angle 10 $f_1 i_2$) and the tissue thickness for each of these sections is markedly different, then the smallest value of the group was used to obtain a conservative radiation dose.

The three body points that were used were the Chest 0, Eye, and Waist 4 of the seated 75-percentile man (see Ref. 1 for definition of these points and the 75-percentile man).

Table 1 presents all the information needed for the radiation dosage computer code. Figure 5 is a side view defining $\theta$.

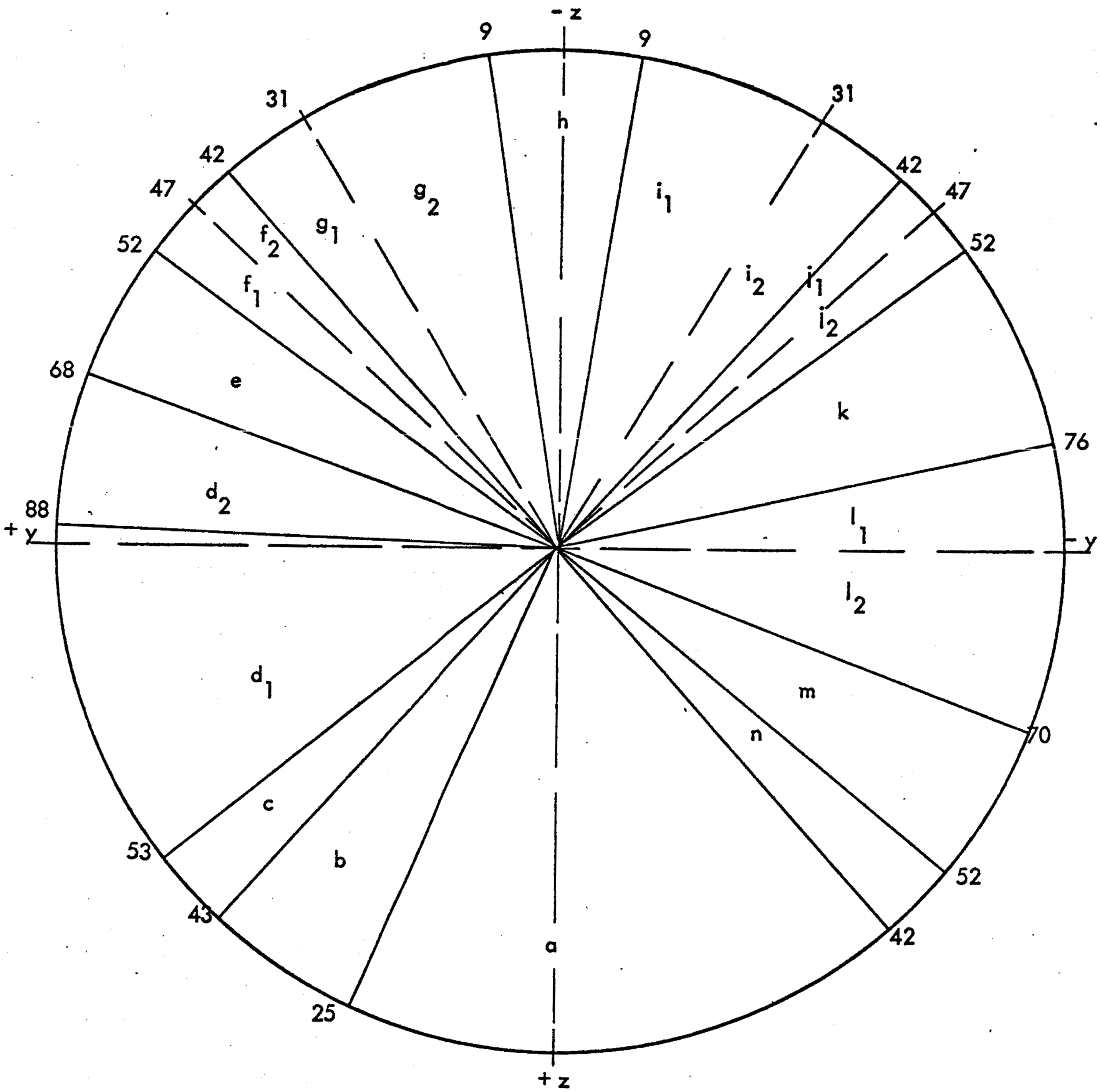


FIGURE 3. Top view of command module azimuthal angles.

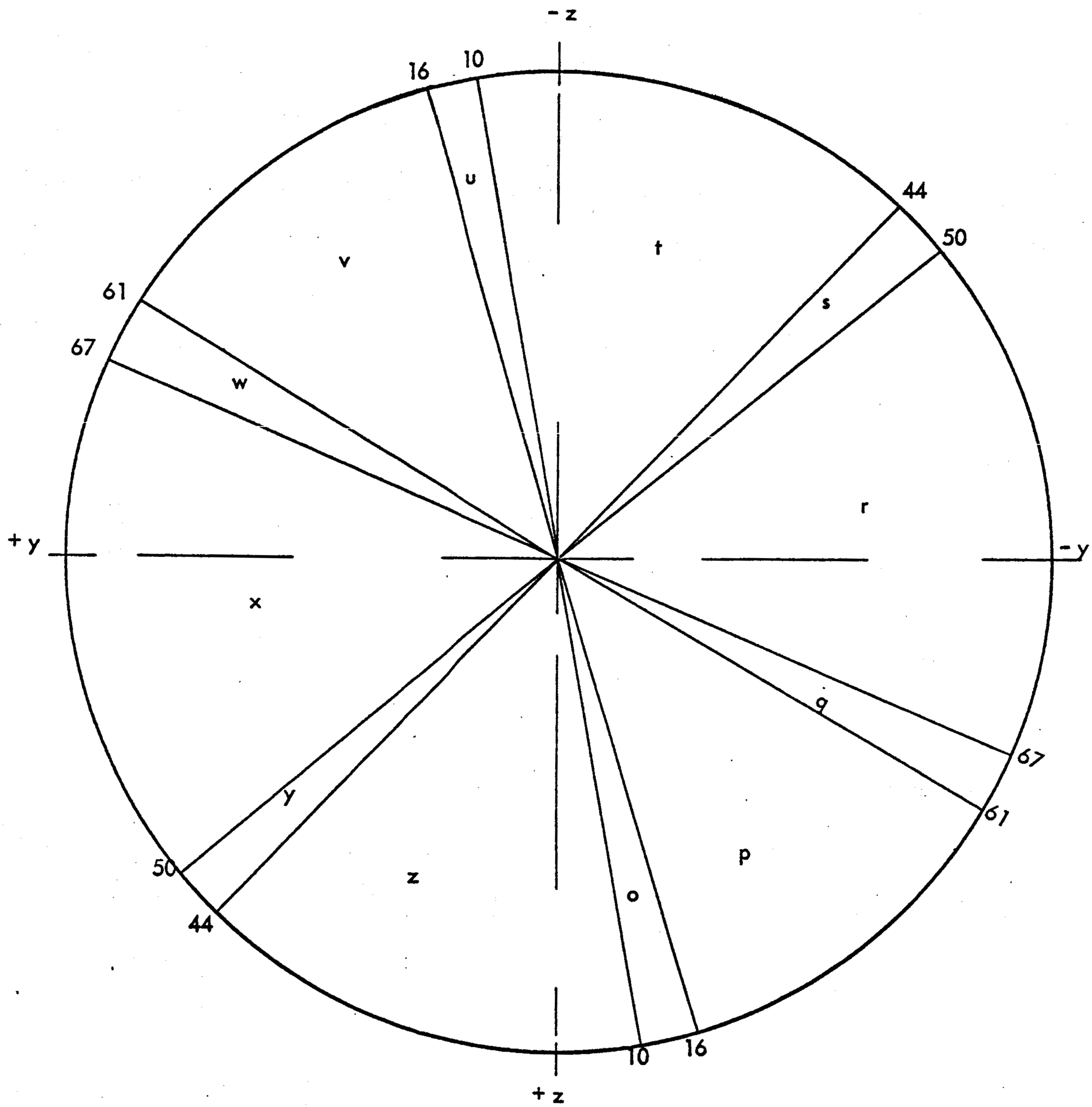


FIGURE 4. Top view of service module azimuthal angles.

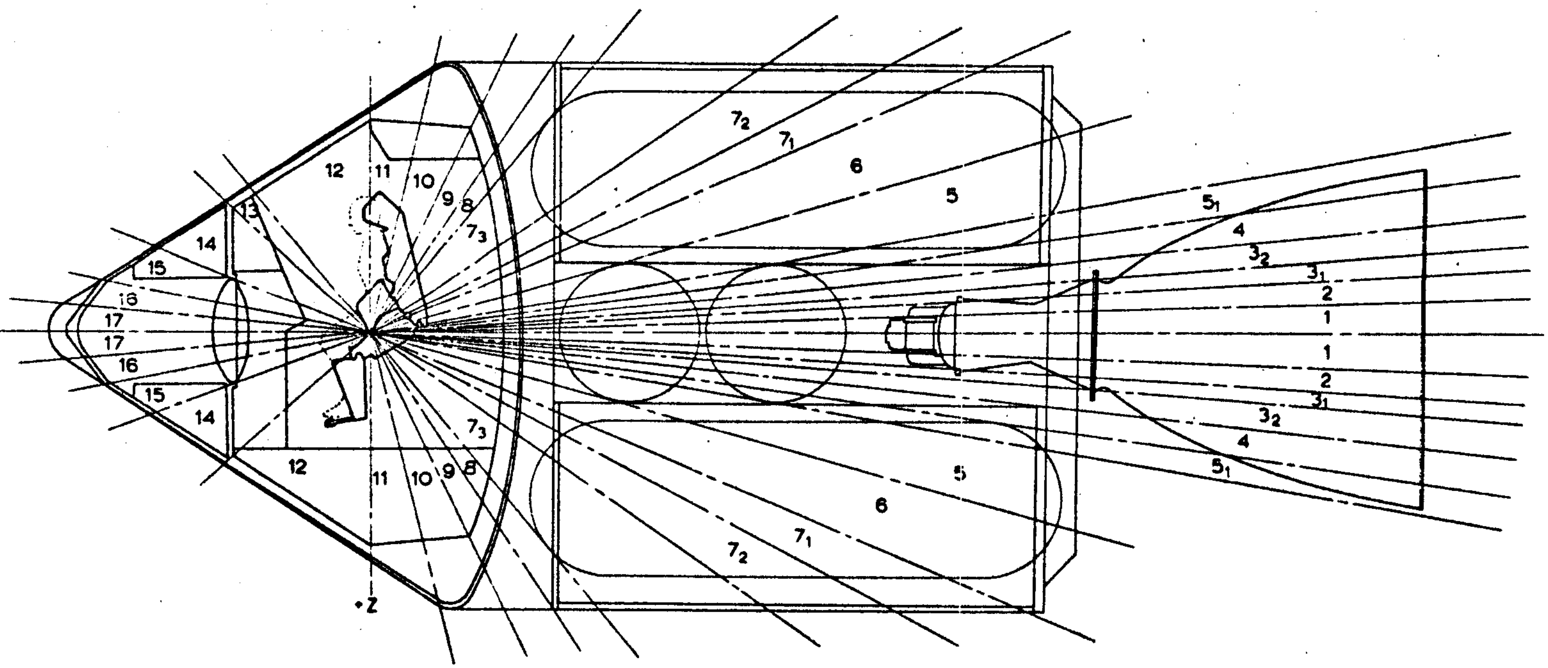


FIGURE 5. Side view of Apollo vehicle.

TABLE 1. Apollo Sector Analysis Data

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| 1 | 178 | 180 | 360 | 0.03048 | 141.04 | 125.24 | 20 | 8 | 25 |
| 2 | 176 | 178 | 360 | 0.09151 | 116.92 | 101.49 | 19 | 8 | 25 |
| $3_1$ | 175 | 176 | 360 | 0.06852 | 50.05 | 35.24 | 19 | 8 | 25 |
| $3_2$ | 173 | 175 | 360 | 0.18199 | 44.79 | 29.99 | 18 | 8 | 25 |
| 4 opqyz | 172 | 173 | 117 | 0.03708 | 44.08 | 31.56 | 18 | 8 | 25 |
| 4 stu | 172 | 173 | 66 | 0.02093 | 44.08 | 31.56 | 18 | 8 | 25 |
| 4 w | 172 | 173 | 6 | 0.00191 | 44.08 | 31.56 | 20 | 8 | 25 |
| 4 rx | 172 | 173 | 126 | 0.03995 | 68.06 | 31.34 | 18 | 8 | 25 |
| 4 v | 172 | 173 | 45 | 0.01424 | 89.89 | 77.275 | 20 | 8 | 25 |
| 5 tz | 164 | 170 | 108 | 0.35324 | 184.82 | 20.82 | 20 | 7 | 25 |
| 5 rx | 164 | 170 | 126 | 0.41213 | 243.19 | 21.00 | 18 | 7 | 25 |
| 5 oqsuwy | 164 | 170 | 36 | 0.11777 | 24.95 | 20.77 | 18 | 7 | 25 |
| $5_1$ oqsuwy | 170 | 172 | 36 | 0.02730 | 24.95 | 20.77 | 18 | 7 | 25 |
| $5_1$ p | 170 | 172 | 45 | 0.03414 | 41.08 | 32.72 | 20 | 7 | 25 |
| $5_1$ v | 170 | 172 | 45 | 0.03414 | 127.18 | 118.82 | 18 | 8 | 25 |
| $5_1$ tz | 170 | 172 | 108 | 0.08189 | 87.99 | 43.93 | 18 | 7 | 25 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| $5_1$ rx | 170 | 172 | 126 | 0.09557 | 133.17 | 34.11 | 18 | 7 | 25 |
| $5_2$ pv | 167 | 170 | 90 | 0.13051 | 112.09 | 106.87 | 18 | 7 | 25 |
| $5_3$ pv | 164 | 167 | 90 | 0.16385 | 146.59 | 110.78 | 17 | 7 | 25 |
| 6 tz | 159 | 164 | 108 | 0.41524 | 32.49 | 6.89 | 20 | 8 | 25 |
| 6 rx | 159 | 164 | 126 | 0.48439 | 413.09 | 7.09 | 13 | 7 | 25 |
| 6 oqsuwy | 159 | 164 | 36 | 0.13839 | 5.68 | 5.68 | 16 | 7 | 25 |
| $6_1$ p | 162 | 164 | 45 | 0.06374 | 94.59 | 22.79 | 14 | 7 | 25 |
| $6_2$ p | 159 | 162 | 45 | 0.10926 | 103.19 | 9.59 | 15 | 7 | 25 |
| 6 v | 159 | 164 | 45 | 0.17300 | 124.39 | 52.59 | 20 | 8 | 25 |
| 7 rx | 133 | 159 | 126 | 4.40263 | 224.36 | 6.3 | 11 | 9 | 25 |
| 7 t | 133 | 159 | 54 | 1.88686 | 143.27 | 6.27 | 14 | 8 | 25 |
| 7 z | 133 | 159 | 54 | 1.88686 | 143.56 | 6.54 | 20 | 10 | 29 |
| 7 oqy | 133 | 159 | 18 | 0.62898 | 5.61 | 5.61 | 12 | 8 | 27 |
| 7 suw | 133 | 159 | 18 | 0.62898 | 5.32 | 5.32 | 14 | 9 | 25 |
| $7_1$ pv | 153 | 159 | 90 | 0.53214 | 69.17 | 12.14 | 15 | 8 | 25 |
| $7_2$ p | 146 | 153 | 45 | 0.38730 | 15.09 | 8.59 | 11 | 7 | 27 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| $7_2$ v | 146 | 153 | 45 | 0.38730 | 14.80 | 8.31 | 19 | 11 | 25 |
| $7_3$ p | 133 | 146 | 45 | 0.91904 | 10.55 | 7.31 | 7 | 7 | 30 |
| $7_3$ v | 133 | 146 | 45 | 0.91904 | 10.26 | 7.02 | 17 | 14 | 25 |
| 8 p | 123 | 133 | 45 | 0.85848 | 7.29 | 7.29 | 6 | 7 | 32 |
| 8 v | 123 | 133 | 45 | 0.85848 | 6.92 | 6.92 | 15 | 19 | 19 |
| 8 rx | 123 | 133 | 126 | 2.40380 | 6.46 | 6.46 | 7 | 11 | 26 |
| 8 oqy | 123 | 133 | 18 | 0.34338 | 9.01 | 9.01 | 12 | 10 | 31 |
| 8 suw | 123 | 133 | 18 | 0.34338 | 8.63 | 8.63 | 11 | 14 | 22 |
| 8 t | 123 | 133 | 54 | 1.03021 | 6.57 | 6.57 | 10 | 9 | 25 |
| 8 z | 123 | 133 | 54 | 1.03021 | 6.95 | 6.95 | 20 | 15 | 37 |
| 9 opqyz | 115 | 123 | 117 | 1.98283 | 11.12 | 11.12 | 15 | 13 | 36 |
| 9 stuvw | 115 | 123 | 117 | 1.98283 | 10.45 | 10.45 | 10 | 17 | 18 |
| 9 rx | 115 | 123 | 126 | 2.13530 | 10.69 | 10.69 | 6 | 13 | 26 |
| 10 a | 105 | 115 | 67 | 1.52423 | 29.254 | 29.254 | 18 | 11 | 55 |
| 10 b | 105 | 115 | 18 | 0.40951 | 20.695 | 20.695 | 35 | 30 | 35 |
| 10 c | 105 | 115 | 10 | 0.22751 | 11.384 | 11.384 | 15 | 30 | 34 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| 10 $d_1$ | 105 | 115 | 39 | 0.88721 | 17.106 | 17.106 | 10 | 30 | 18 |
| 10 $d_2$ | 105 | 115 | 20 | 0.45502 | 15.835 | 15.835 | 11 | 27 | 16 |
| 10 e | 105 | 115 | 16 | 0.36399 | 13.438 | 13.438 | 11 | 30 | 13 |
| 10 $f_1$ $i_2$ | 105 | 115 | 10 | 0.22751 | 10.282 | 10.282 | 2 | 12 | 13 |
| 10 $f_2 g_1$ $i_2$ $i_1$ | 105 | 115 | 32 | 0.72798 | 5.934 | 5.934 | 3 | 12 | 12 |
| 10 $g_2$ $hi_1$ | 105 | 115 | 62 | 1.41051 | 12.492 | 12.492 | 5 | 15 | 10 |
| 10 k | 105 | 115 | 24 | 0.54598 | 14.756 | 14.756 | 1 | 10 | 13 |
| 10 l | 105 | 115 | 34 | 0.77349 | 17.666 | 17.666 | 0 | 5 | 17 |
| 10 m | 105 | 115 | 18 | 0.40951 | 14.642 | 14.642 | 0 | 5 | 23 |
| 10 n | 105 | 115 | 10 | 0.22751 | 15.364 | 15.364 | 1 | 6 | 34 |
| 11 a | 90 | 105 | 67 | 2.40849 | 44.686 | 44.686 | 30 | 17 | 10 |
| 11 b | 90 | 105 | 18 | 0.64704 | 25.954 | 25.954 | 30 | 30 | 15 |
| 11 c | 90 | 105 | 10 | 0.35945 | 13.252 | 13.252 | 9 | 33 | 12 |
| 11 $d_1$ | 90 | 105 | 39 | 1.40192 | 10.797 | 10.797 | 8 | 30 | 6 |
| 11 $d_2$ | 90 | 105 | 20 | 0.71898 | 11.969 | 11.969 | 8 | 30 | 7 |
| $11_e$ | 90 | 105 | 16 | 0.57519 | 9.519 | 9.519 | 9 | 35 | 3 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| 11 $f_1$ $i_2$ | 90 | 105 | 10 | 0.35945 | 3.929 | 3.939 | 0 | 13 | 2 |
| 11 $f_2$ $g_1$ $i_2$ $i_1$ | 90 | 105 | 32 | 1.15029 | 2.329 | 2.329 | 2 | 15 | 1 |
| 11 $g_2$ $hi_1$ | 90 | 105 | 62 | 2.22873 | 5.770 | 5.770 | 5 | 25 | 1 |
| 11 k | 90 | 105 | 24 | 0.86270 | 8.179 | 8.179 | 0 | 11 | 3 |
| 11 l | 90 | 105 | 34 | 1.22223 | 11.149 | 11.149 | 0 | 5 | 6 |
| 11 m | 90 | 105 | 18 | 0.64704 | 12.322 | 12.322 | 0 | 5 | 7 |
| 11 n | 90 | 105 | 10 | 0.35945 | 19.052 | 19.052 | 0 | 6 | 12 |
| 12 a | 43 | 90 | 67 | 6.80563 | 30.779 | 30.779 | 8 | 20 | 2 |
| 12 b | 43 | 90 | 18 | 1.82837 | 24.459 | 24.459 | 3 | 35 | 0 |
| 12 c | 43 | 90 | 10 | 1.01573 | 14.799 | 14.799 | 3 | 40 | 0 |
| 12 $d_1$ | 43 | 90 | 39 | 3.96145 | 23.329 | 23.329 | 1 | 26 | 0 |
| 12 $d_2$ | 50 | 90 | 20 | 1.78556 | 13.707 | 13.707 | 1 | 25 | 0 |
| 12 $ef_1$ | 50 | 90 | 21 | 1.87478 | 8.087 | 8.087 | 1 | 30 | 0 |
| 12 $f_2$ $gii_1$ | 50 | 90 | 76 | 6.78502 | 1.587 | 1.587 | 2 | 12 | 0 |
| 12 h | 50 | 90 | 18 | 1.60699 | 6.408 | 6.408 | 2 | 30 | 0 |
| 12 $i_2$ | 50 | 90 | 5 | 0.44635 | 1.587 | 1.587 | 0 | 9 | 0 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2 \times 10^2$ | SHIELDING THICKNESS FUELED | SHIELDING THICKNESS UNFUELED | TISSUE THICKNESS EYE | TISSUE THICKNESS WAIST | TISSUE THICKNESS CHEST |
|---|---|---|---|---|---|---|---|---|---|
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| 12 k | 50 | 90 | 24 | 2.14263 | 8.379 | 8.379 | 0 | 8 | 0 |
| 12 $l_1$ | 50 | 90 | 14 | 1.24984 | 10.792 | 10.792 | 0 | 6 | 0 |
| 12 $l_2$ | 43 | 90 | 20 | 2.03154 | 10.792 | 10.792 | 0 | 5 | 0 |
| 12 m | 43 | 90 | 18 | 1.82837 | 7.982 | 7.982 | 0 | 5 | 0 |
| 12 n | 43 | 90 | 10 | 1.01573 | 11.102 | 11.102 | 0 | 6 | 0 |
| 13 | 43 | 50 | 180 | 2.21401 | 13.787 | 13.787 | 0 | 6 | 0 |
| 14 a | 22 | 43 | 67 | 1.82233 | 11.304 | 11.304 | 0 | 20 | 0 |
| 14 b | 22 | 43 | 18 | 0.48956 | 9.490 | 9.490 | 0 | 18 | 0 |
| 14 cn | 22 | 43 | 20 | 0.54399 | 4.320 | 4.320 | 0 | 6 | 0 |
| 14 d | 22 | 43 | 59 | 1.60476 | 17.378 | 17.378 | 0 | 12 | 0 |
| 14 e | 22 | 43 | 16 | 0.43521 | 20.140 | 20.140 | 0 | 14 | 0 |
| 14 k | 22 | 43 | 24 | 0.65277 | 20.140 | 20.140 | 0 | 6 | 0 |
| 14 fj | 22 | 43 | 20 | 0.54399 | 15.402 | 15.402 | 0 | 6 | 0 |
| 14 gi | 22 | 43 | 66 | 1.79511 | 21.897 | 21.897 | 0 | 8 | 0 |
| 14 h | 22 | 43 | 18 | 0.48956 | 17.792 | 17.792 | 0 | 12 | 0 |
| 14 l | 22 | 43 | 34 | 0.92477 | 12.422 | 12.422 | 0 | 6 | 0 |

TABLE 1. Apollo Sector Analysis Data (cont'd)

| SOLID ANGLE | $\theta_1$ | $\theta_2$ | $\Delta\Psi$ | $\Delta\Omega_2$ x $10^2$ | SHIELDING THICKNESS | | TISSUE THICKNESS | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | FUELED | UNFUELED | EYE | WAIST | CHEST |
| | degrees | degrees | degrees | steradians | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ | $gm/cm^2$ |
| 14 m | 22 | 43 | 18 | 0.48956 | 21.236 | 21.236 | 0 | 6 | 0 |
| 15 ab | 11 | 22 | 85 | 0.64283 | 11.123 | 11.123 | 0 | 8 | 0 |
| 15 d | 11 | 22 | 59 | 0.44619 | 9.791 | 9.791 | 0 | 9 | 0 |
| 15 lm | 11 | 22 | 52 | 0.39327 | 9.791 | 9.791 | 0 | 7 | 0 |
| 15 e | 11 | 22 | 16 | 0.12104 | 9.231 | 9.231 | 0 | 10 | 0 |
| 15 k | 11 | 22 | 24 | 0.18152 | 9.231 | 9.231 | 0 | 7 | 0 |
| 15 cn | 11 | 22 | 20 | 0.15128 | 4.043 | 4.043 | 0 | 8 | 0 |
| 15 fj | 11 | 22 | 20 | 0.15128 | 3.057 | 3.057 | 0 | 8 | 0 |
| 15 gi | 11 | 22 | 66 | 0.49911 | 5.841 | 5.841 | 0 | 8 | 0 |
| 15 h | 11 | 22 | 18 | 0.13616 | 1.781 | 1.781 | 0 | 9 | 0 |
| 16 | 5 | 11 | 360 | 0.72798 | 2.833 | 2.833 | 0 | 8 | 0 |
| 17 | 0 | 5 | 360 | 0.19051 | 3.4845 | 3.4845 | 0 | 8 | 0 |

## DERIVATION OF FRACTIONAL SOLID ANGLE FORMULA

The following derivation will facilitate processing the NASA angles $\theta_1$, $\theta_2$, and $\Delta\Psi$, directly into the computer program from Table 1. Using a unit sphere (see Fig. 6) a fractional solid angle can be defined as

$$dA = \sin\theta \; d\theta \; d\Psi$$

$$\text{Area of a zone of the sphere} = \int_0^{2\pi} \int_{\theta_1}^{\theta_2} \sin\theta \; d\theta \; d\Psi \qquad \theta_1 \leq \theta_2$$

$$= 2\pi(\cos\theta_1 - \cos\theta_2)$$

then upon dividing by $4\pi$ and further dividing the zone, the fractional solid angle

$$\Delta\Omega = 1/2\,(\cos\theta_1 - \cos\theta_2)\frac{\Delta\Psi}{360} \qquad \Delta\Psi \text{ in degrees}$$

so that $\sum \Delta\Omega = 1.$

The computer code described in the appendix calculates $\Delta\Omega$ for each sector and, if desired, an instruction card can be inserted into the deck to punch this data on IBM cards in the same format as the radiation dosage computer codes.

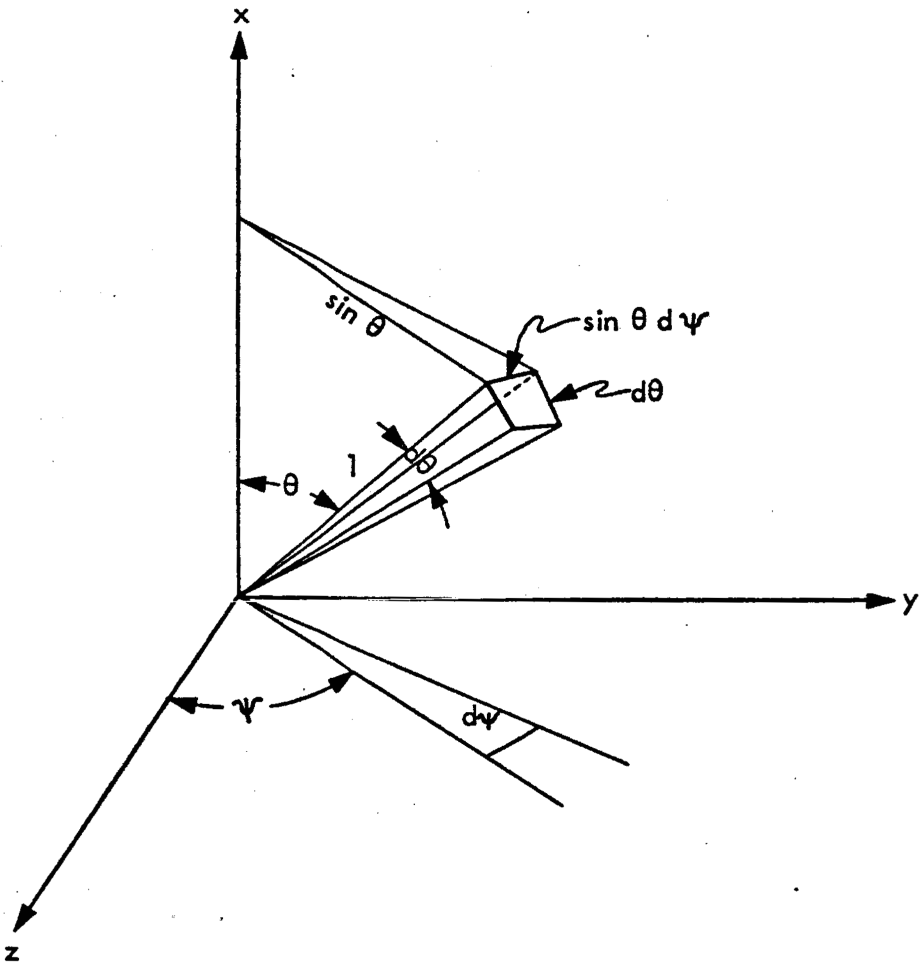


FIGURE 6. Geometry for fractional solid angle derivation.

## APPENDIX

## SECTOR ANALYSIS COMPUTER CODE DESCRIPTION

### GENERAL INFORMATION

#### Purpose

The code does essentially two things. It first calculates the fractional solid angle (sometimes referred to as the weighting factor), $\Delta\Omega$, for each sector, and then it transforms the given coordinate system from one in $\psi$ and $\omega$ to one in $\phi$ and $\theta$.

#### Limitations

Due to the program's limitations, the angles $\phi$ and $\theta$ must lie between -90 and +90 degrees; hence, all input angles are assumed to be in the first quadrant and $\omega \neq 90$. For the case when $\omega = 90°$, we see from the geometry that $\phi = 90°$ and $\theta = 90° - \psi$.

#### Method

The program is coded in FORTRAN for the IBM 7094 and conforms to the FORMON system. The equations to be solved are:

For the first part,

$$\Delta\Omega = 1/2\,(\cos\theta_1 - \cos\theta_2)\frac{\Delta\Psi}{360}$$

For the second part, the pair of equations,

$$\phi = \tan^{-1}(\tan\omega\ \sin\psi)$$

$$\theta = \tan^{-1}(\tan\omega\cos\phi\cos\psi)$$

## INPUT PREPARATION AND OUTPUT DESCRIPTION

Input is from punched IBM cards, punched according to the section on operating information. Input parameters are $\theta_1$, $\theta_2$, $\Delta\psi$, $\omega$, and $\psi$ (all angles are in degrees). The output is on standard IBM output paper. Output parameters are $\theta_1$, $\theta_2$, $\Delta\psi$, $\Delta\Omega$, $\sum\Delta\Omega$, $\psi$, $w$, $\phi$, and $\theta$.

## OPERATING INFORMATION

The deck setup consists of the following arrangement:

1. FORMON control cards
2. Program deck
3. Transfer to data card
4. Data (consisting of the following):
   a. Card type I
   b. Card type II
   c. Card type III
   d. Card type IV
   e. Card type V
   f. Card type VI
   g. Card type VII

Where each of the card types are punched as follows:

a. Card type I

| Columns | Format | Variable |
|---|---|---|
| 1- 6 | Fixed point integer with no decimal point, punched right adjusted in field. | Number of $\Delta\Omega$'s (also No. of $\theta_1$'s, $\theta_2$'s, and $\Delta\Psi$'s) |

b. Card type II (may be more than one card)

| Columns | Format | Variable |
|---|---|---|
| 1- 6 | XX.XX or any arrangement of five numbers and a decimal point. | 1st $\Delta\Psi$ |
| 7-12 | " | 2nd $\Delta\Psi$ |
| 13-18 | " | 3rd $\Delta\Psi$ |
| 19-24 | " | 4th $\Delta\Psi$ |
| 25-30 | " | 5th $\Delta\Psi$ |
| 31-36 | " | 6th $\Delta\Psi$ |
| 37-42 | " | 7th $\Delta\Psi$ |
| 43-48 | " | 8th $\Delta\Psi$ |
| 49-54 | " | 9th $\Delta\Psi$ |
| 55-60 | " | 10th $\Delta\Psi$ |
| 61-66 | " | 11th $\Delta\Psi$ |
| 67-72 | " | 12th $\Delta\Psi$ |

As many cards as necessary may be used to include all the $\Delta\Psi$'s for a particular program run up to a maximum of 200 $\Delta\Psi$'s. (The number of $\Delta\Psi$'s must coincide with the number on card type I).

c. Card type III (may be more than one card). Same as card type II except the values of $\theta_1$ are used in place of $\Delta\Psi$. (The same restrictions apply.)

d. Card type IV (may be more than one card). Same as card type II except the values of $\theta_2$ are used in place of $\Delta\Psi$. (The same restrictions apply.)

e. Card type V

| Columns | Format | Variable |
|---|---|---|
| 1- 6 | Fixed point integer with no decimal point, punched right adjusted in field. | Number of $\psi$'s |
| 7-12 | " | Number of $\omega$'s |

f. Card type VI (may be more than one card)

| Columns | Format | Variable |
|---|---|---|
| 1-10 | XX.XX or any arrangement of nine numbers and a decimal point. | 1st $\omega$ |
| 11-20 | " | 2nd $\omega$ |
| 21-30 | " | 3rd $\omega$ |
| 31-40 | " | 4th $\omega$ |
| 41-50 | " | 5th $\omega$ |
| 51-60 | " | 6th $\omega$ |

As many cards as necessary may be used to include all the $\omega$'s for a particular program run up to a maximum of 50 $\omega$'s. (The number of $\omega$'s must coincide with the number on the card type V.)

g. Card Type VII (may be more than one card). Same as card type VI except the values of $\psi$ are used in place of $\omega$. (The same restrictions apply as in card type VI.)

Machine Setup and Run Information

The console switch settings are normal. No special tape units are required other than the normal input tape 5 and the output tape 6 requirements. There is no on-line equipment required.

The running time (including compilation time) for 108 values each of $\theta_1$, $\theta_2$, and $\Delta\Psi$, 19 values of $\Psi$ and 23 values of $\omega$ was 0.66 minutes. There were 428 lines of output. There are no programmed success or error stops. Program success transfers control back to the FORMON monitor.

Program Information

Storage assignments are:

Main program $(2670)_8$

Monitor $(2000)_8$

Library routines called by the program are: (FPT), (TSHM), (RTN), (STHM), (FIL), COS, SIN, TAN, ATAN.

Calculation to verify computer program:

| Input | Output | Hand Calculation |
|---|---|---|
| $\omega = 22°$ | $\phi = 15.1281°$ | $\phi = 15.13°$ |
| $\Psi = 42°$ | $\theta = 16.1640°$ | $\theta = 16.16°$ |
| $\Delta\Psi = 24°$ | $\Delta\Omega = 0.0018148$ | $\Delta\Omega = 0.001815$ |
| $\theta_1 = 11°$ | | |
| $\theta_2 = 22°$ | | |

## REFERENCES

1. Dye, D. L., "A Geometrical Analysis of the Seated Human Body for Use in Radiation Dosage Calculations, " D2-90107, The Boeing Company, July 1962.